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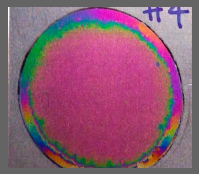
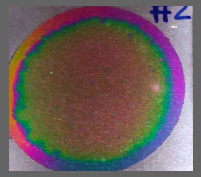
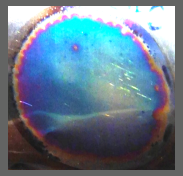






Radioactive target needs for nuclear data

Hye Young Lee

Los Alamos National Laboratory

1. **Normal, stable targets for "differential" nuclear data measurements**
2. **How to make "radioactive" targets; irradiation, separation, fabrication, etc.**
3. **Ongoing target characterization effort and development**

collaborators:

Physics Division:	H.Y. Lee, S. Kuvin, B. DiGiovine, P. Koehler
Chemistry Division:	C. Vermeulen C. Lledo, V. Mocko, E. Birnbaum
Central Michigan Univ.:	G. Perdikakis, P. Tsintari

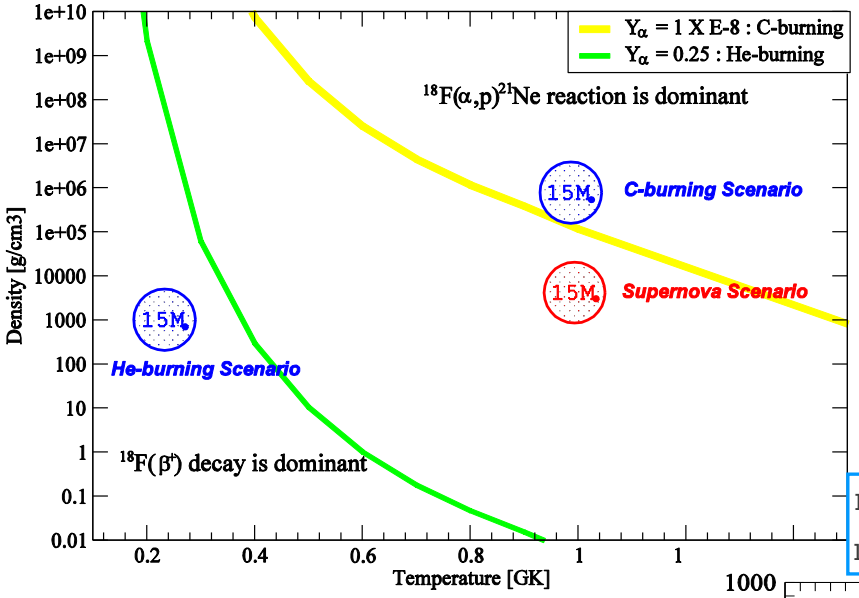
* students, red-postdocs

Los Alamos NATIONAL LABORATORY EST. 1943

NNSA National Nuclear Security Administration

Managed by Triad National Security for the U.S. Department of Energy's NNSA

$^{18}F(\alpha,p)^{21}Ne$ reaction for astrophysical implications

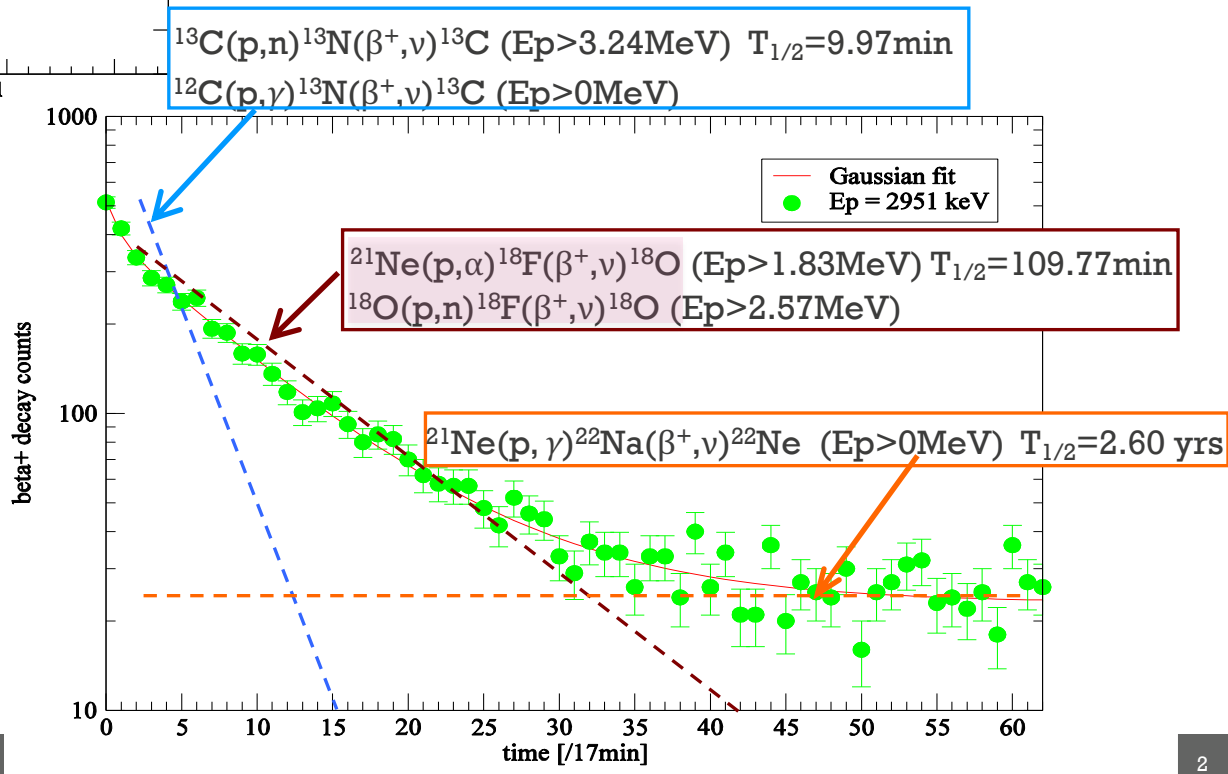


H.Y. Lee, et al. PRC 80 (2), 025805 (2009)

-difficult to directly measure (α,p) reaction on a radioactive target: ^{18}F (β^+) ^{18}O ($T_{1/2}$ = 109.77 min., 100% decay by β+)

-instead measured a time-reversed $^{21}Ne(p,\alpha)^{18}F$ reaction via the activation method at U. of Notre Dame

Biggest proton-beam induced background in the activation method was any contamination of ^{18}O atoms on the ^{21}Ne target, since both produce the same ^{18}F



Stable ^{21}Ne implanted target was characterized by Scanning Electron Microscope(SEM)

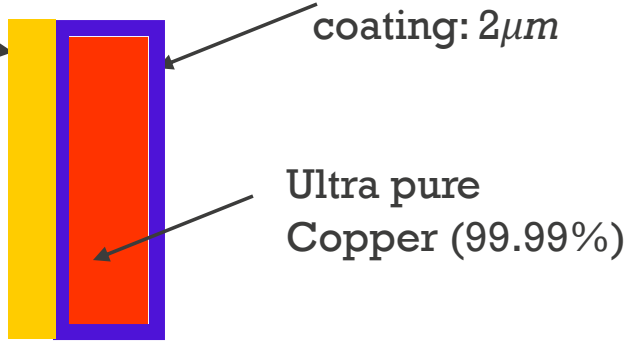
H.Y. Lee et al. NIM B 267, 3539 (2009)

Pure gold coating: 65μm

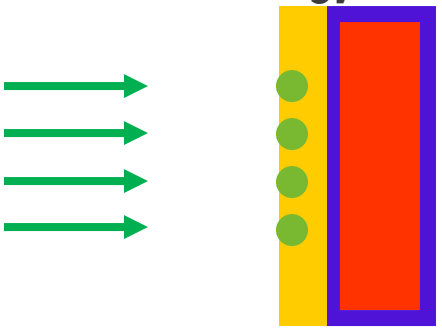
(To stop 3.5MeV protons)

Nickel inner coating: 2μm

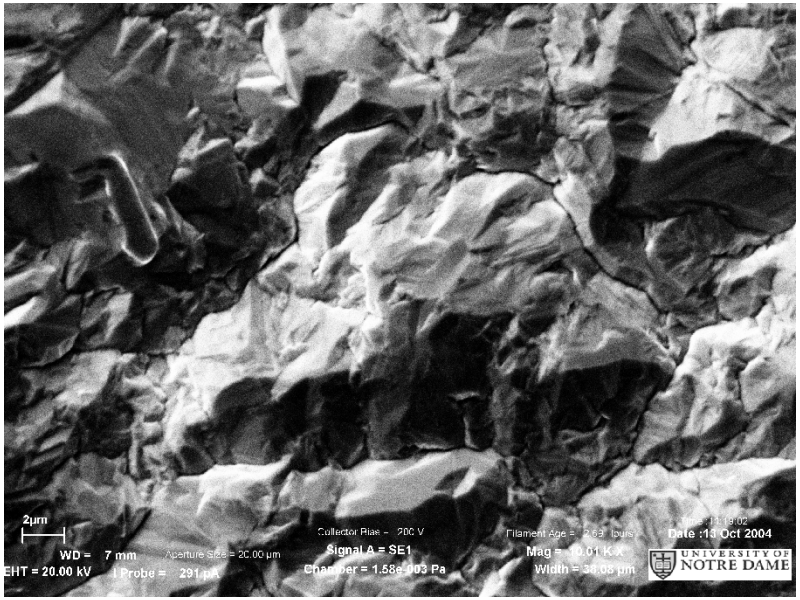
Ultra pure Copper (99.99%)



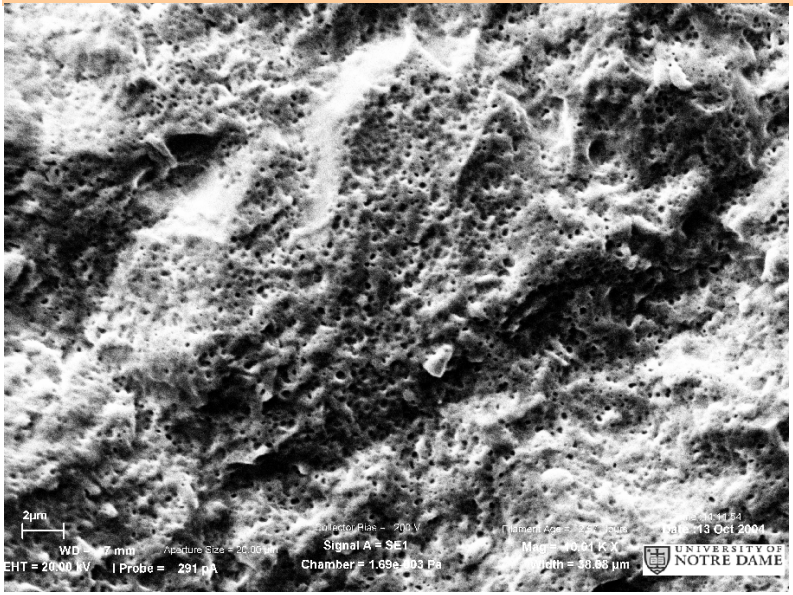
^{21}Ne : 23keV energy loss at Ep=3MeV



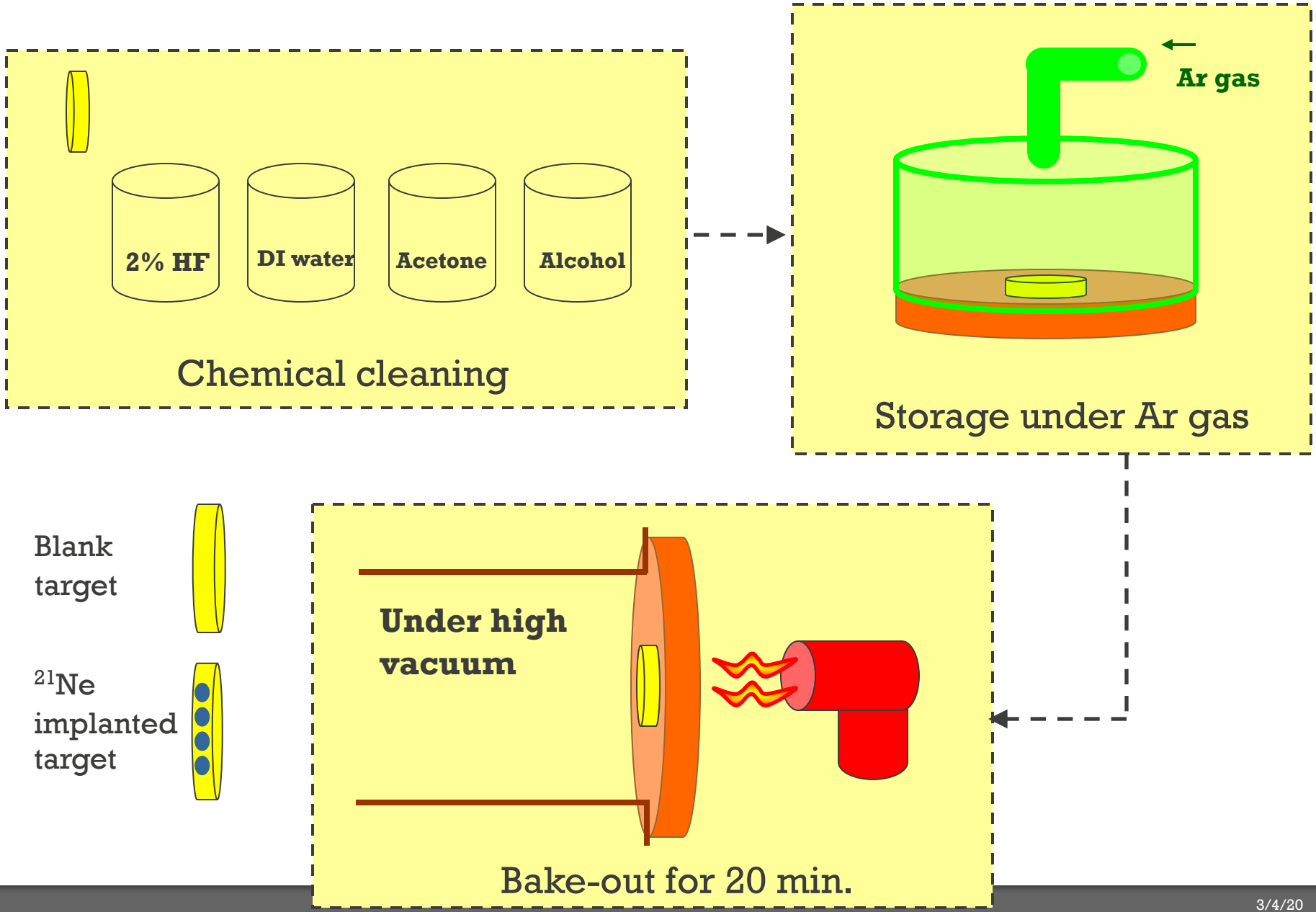
Before implantation: Au/Cu backing



^{21}Ne (@400+150keV), Q=0.24C implanted: Au/Cu backing



Oxygen reduction effort via chemical cleaning and baking



Characterization of reduction in oxygen contaminants

A. Test different chemicals with activation

:bombarding proton(E_p=3MeV) for 4 hours, then counting ^{18}F due to $^{18}O(p,n)$

[1] Blank Au/Cu

[2] Implanted target by ^{20}Ne

[3] Blank, after rinsing with 99.7% acetone

[4] Blank, after baking with heat gun for 20min.

Not efficient to test many different conditions for optimization

B. Test baking procedure with Deuteron-Induced γ-ray Emission(DIGE)

:counting 871keV transition from 1st excited to ground state of $^{16}O(d,p\gamma)$ at E_d=2MeV

[1] Blank Ta

[2] Blank Au/Cu

[3] Blank, after dipping in 2% HF* for 1min and rinsing with DI water

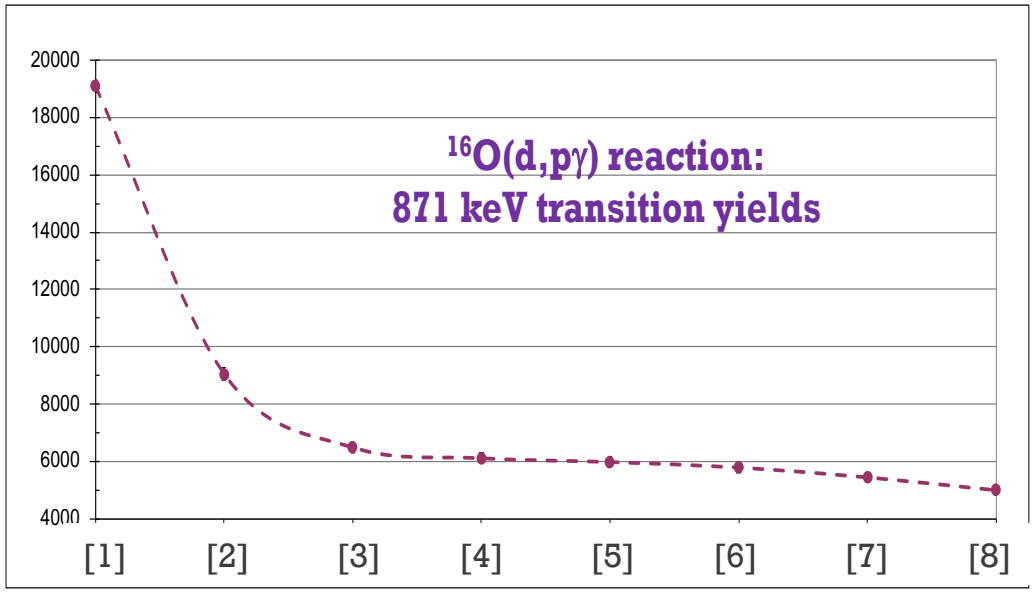
[4] Blank, after [3] and baking for 10min above 100°C

[5] Blank, after [4] and baking for 20min above 100°C

[6] Blank, after dipping in 2% HF for 2min, rinsing with DI water, Acetone, Alcohol under Ar gas flushing

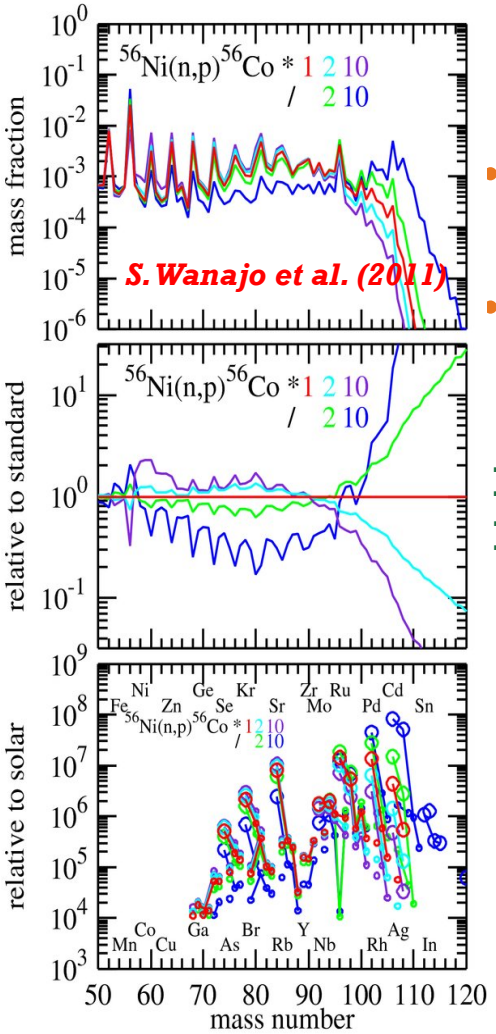
[7] Blank, after [6] and baking for 10mn above 100°C

[8] Blank, after [7] and baking for 20min above 100°C



*:Reference to RCA cleaning procedure for wafers

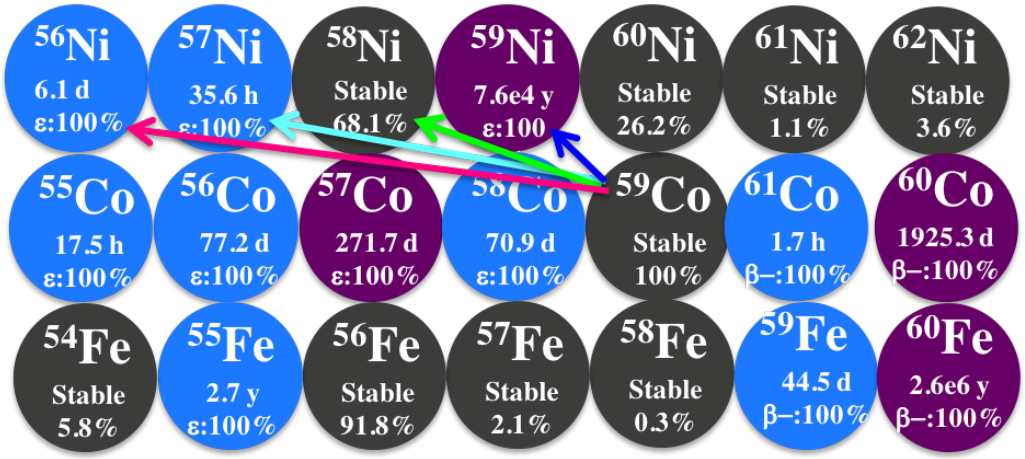
Directly measuring radioactive ^{56}Ni(n,p) reaction cross section at LANSCE, with IPF ^{56}Ni production



νp process with abundant protons at T_9=3 in neutrino-driven winds core-collapse supernovae; $\bar{\nu}_e + p \rightarrow n + e^+$

- Recent observations of Sr, Y, and Zr in metal poor stars suggests an additional process besides s, -r, γ-processes. However, no (n,p) reaction data on proton-rich nuclei exist to test this process
- During the onset of Nuclear Statistical Equilibrium freezeout (T_9=1.5 – 3), ^{56}Ni is the most abundant seed nuclei, so any small neutron reaction of (n,p) would make most impact on yielding a final abundance during νp process

IPF produces radioactive Ni isotopes via ^{59}Co(p,xn) and LENZ measures (n,p) reaction at LANSCE

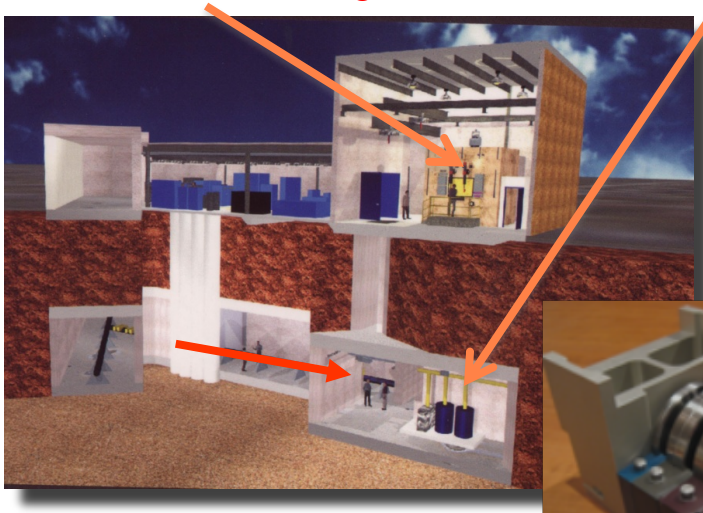


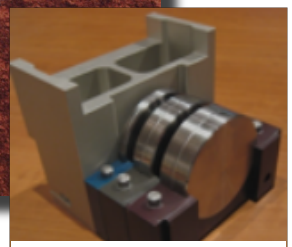
- Until now, this direct measurement was impossible, due to the limited access to radioactive targets (^{56}Ni, $T_{1/2}$ = 6 days) and unavailable neutrons (required energy and flux)

Isotope irradiation at IPF and chemical separation, fabrication at TA48

Hot Cell

Target Irradiation Chamber



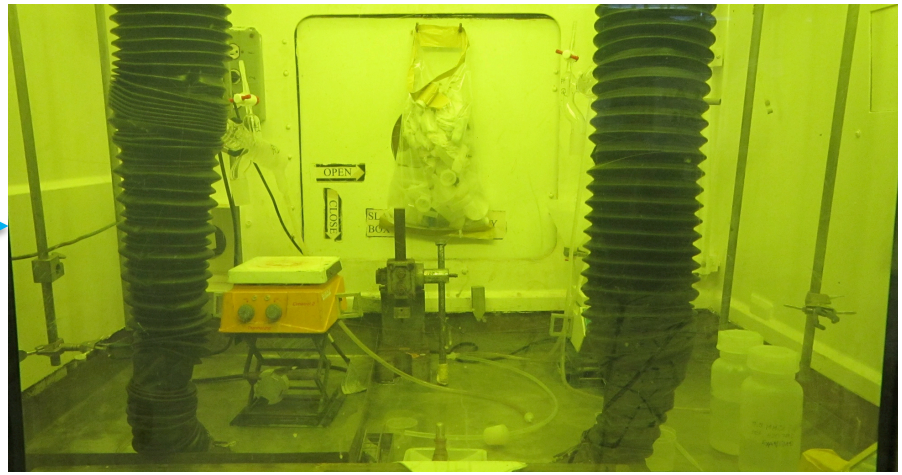


3 Stack Target Irradiation

100 MeV (230 μA) H^+

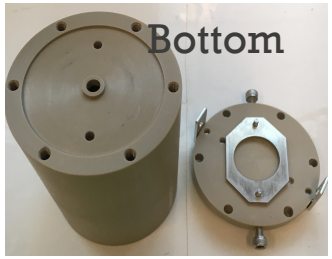
Proton irradiation

separation

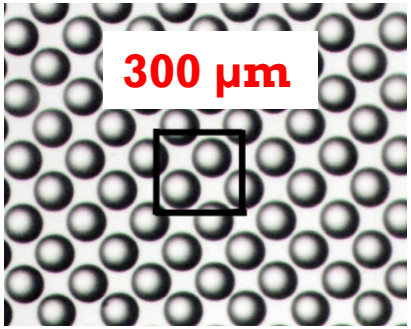


The Hot Cell Facility in TA48 consists of 13 hot cells for radiochemical purification. Isotopes of interest are isolated from targets using remote manipulators and standard wet chemistry techniques such as ion exchange chromatography.

fabrication

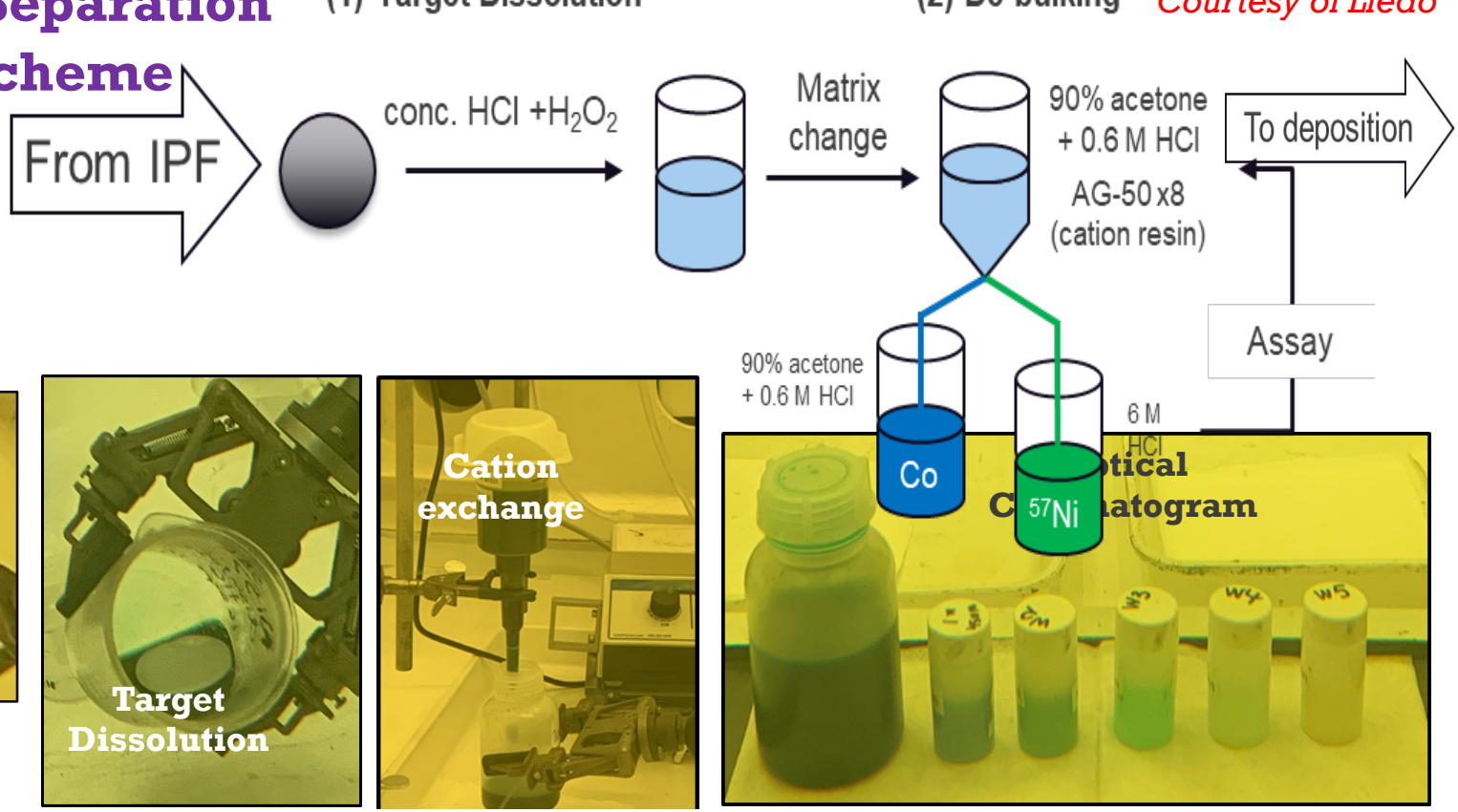


1.Electrodeposition: Developed an optimized electodeposition device to be used in the Hot Cell with radioactive samples for uniformity & no impurity



2. Micro-jet printing: Developing a NEW small-quantity radioactive target fabrication method, which manipulates tiny drops using a transducer for fluid at ambient pressure with 100 % efficiency, introducing some impurities

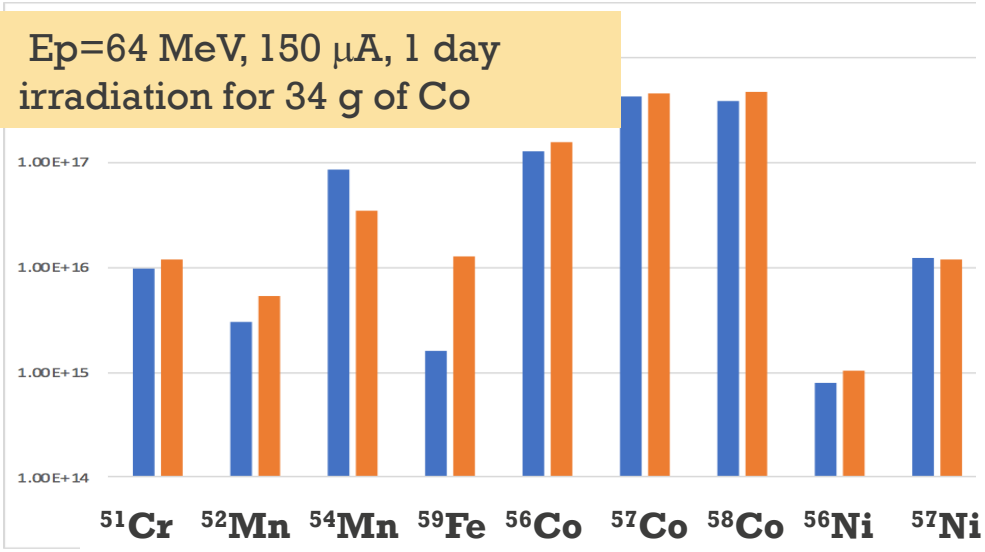
^{56}Ni and ^{57}Ni Separation from Co Scheme



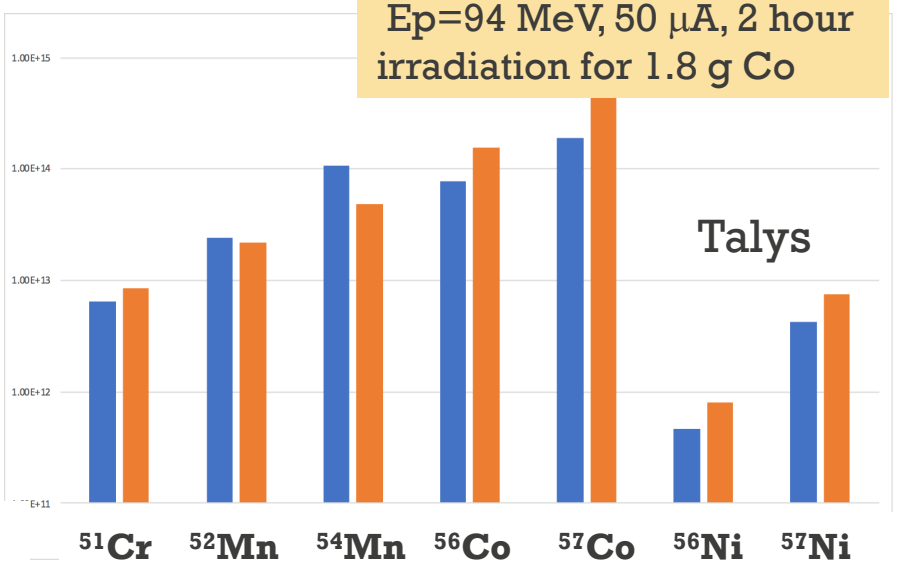
- tracer Ni (~μg) separation from bulky Co (~ g)
- The procedure is Simple and fast (2-3 d)
- Co decontamination factor is high (>9,000)
- We have developed methods to removed anticipated contaminates, (Co, Mn, Cr, V)
- Synchrotron measurements, using the X-ray Absorption Fine Structure (XAFS) analysis, commenced to develop understanding into why the separation works
- Characterization for the separation through γ-spectroscopy (radionuclide contaminants) and ICP-AES (stable contaminants)
- Compatible with remote handling techniques

^{56}Ni and ^{57}Ni production cross section estimates validated with IFP activation data

Ep=64 MeV, 150 μA, 1 day irradiation for 34 g of Co

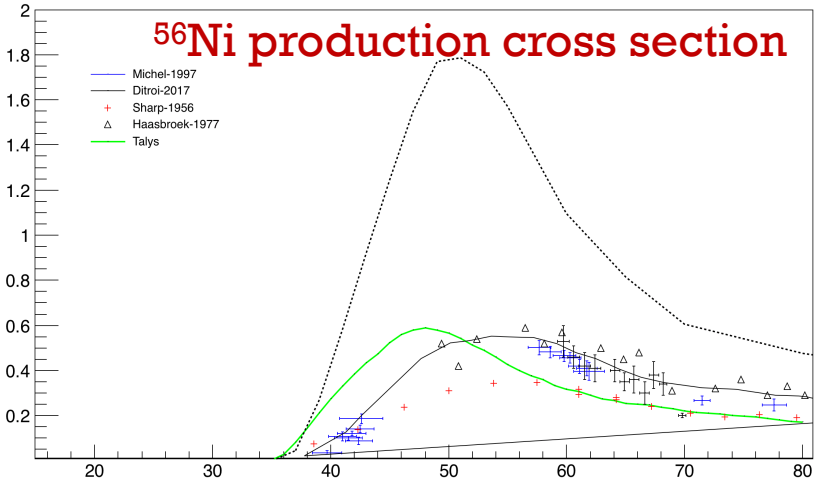


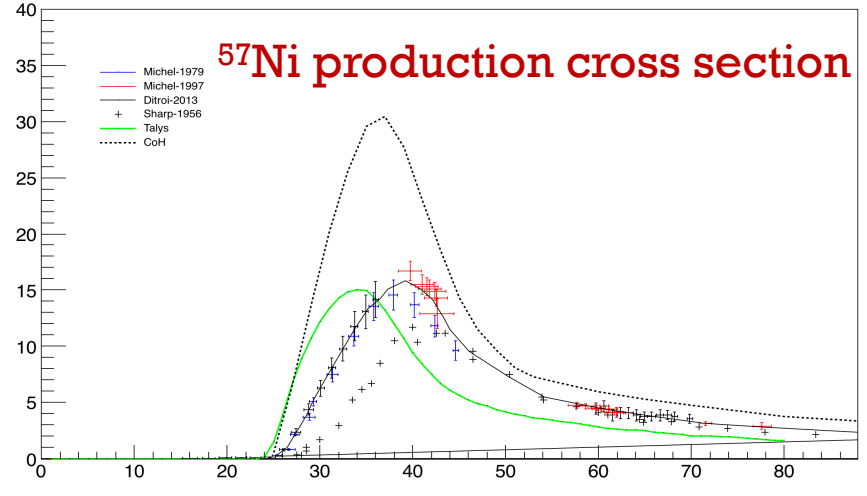
Ep=94 MeV, 50 μA, 2 hour irradiation for 1.8 g Co



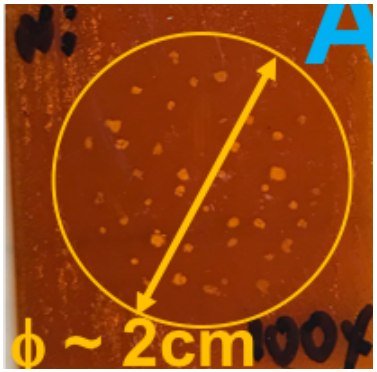
IPF activation data

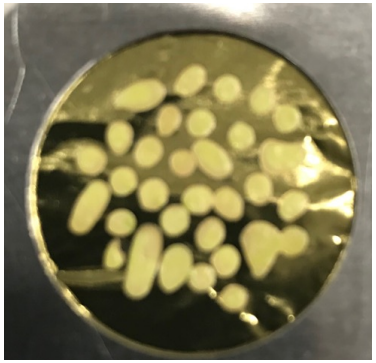
Calculations using interpolated reaction cross sections with available measurements



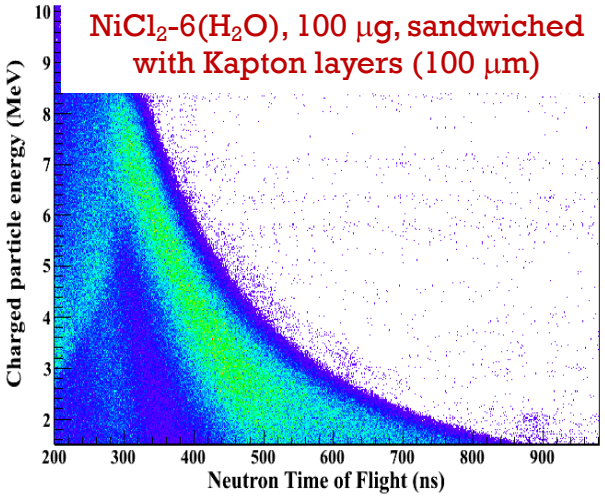


manual stippling method for a small quantity target

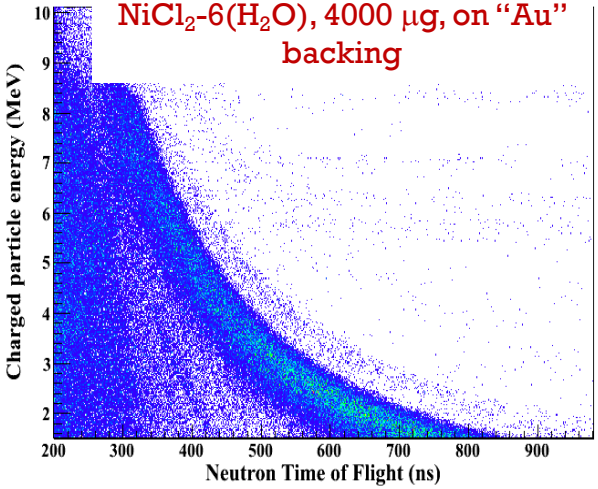




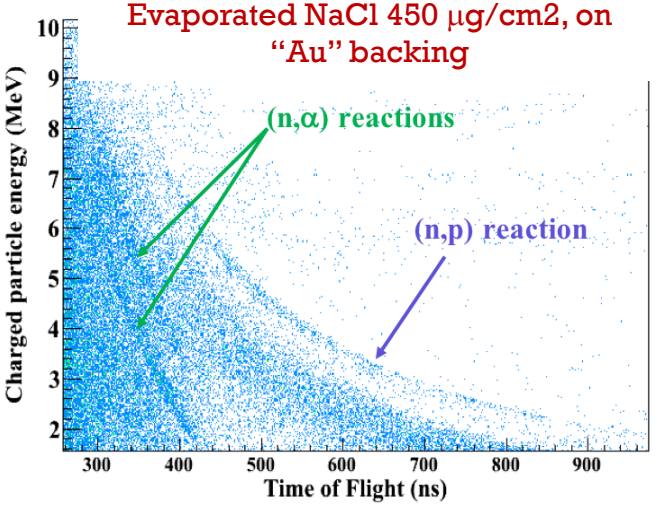
$NiCl_2$-6(H_2O), 100 μg, sandwiched with Kapton layers (100 μm)



$NiCl_2$-6(H_2O), 4000 μg, on "Au" backing



Evaporated NaCl 450 μg/cm2, on "Au" backing

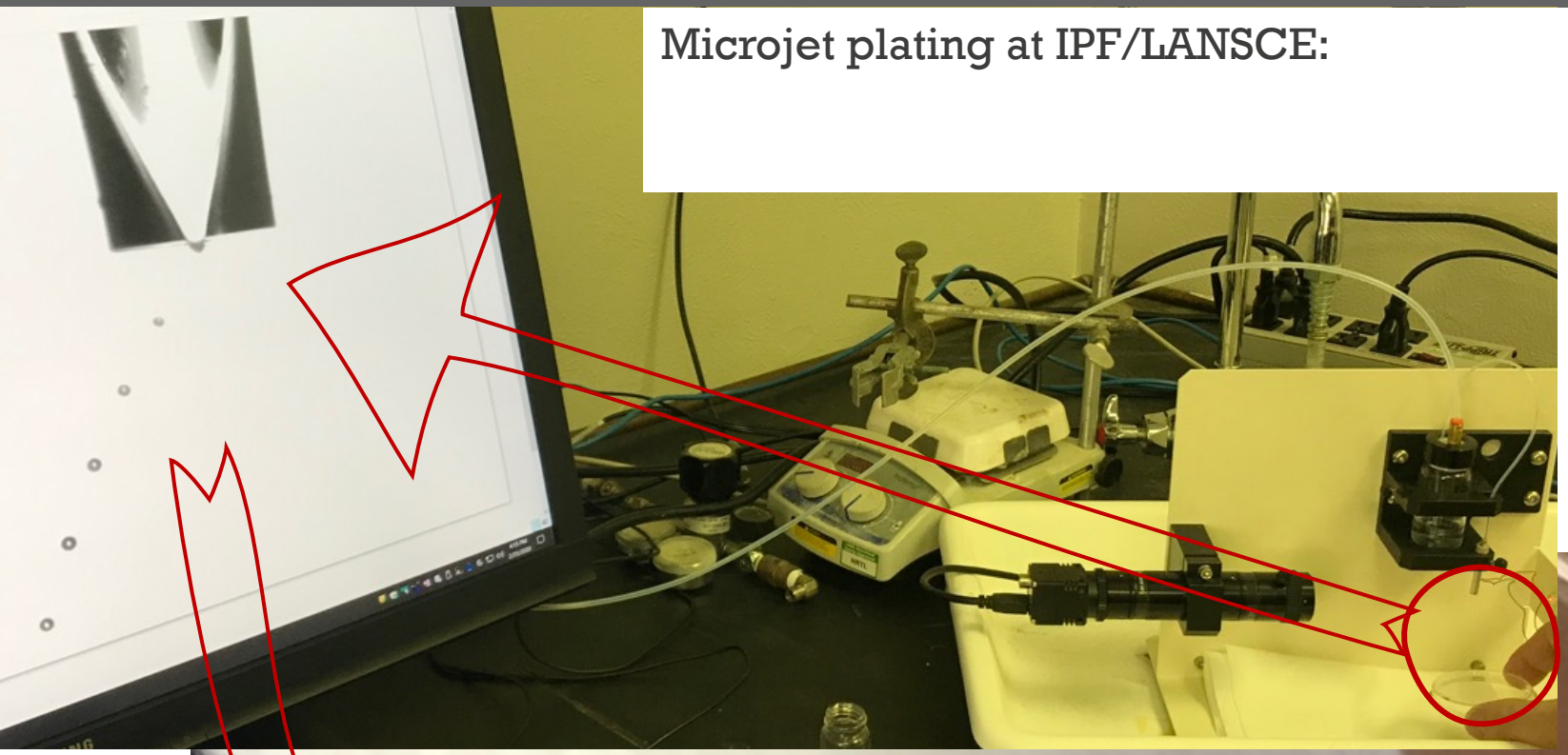


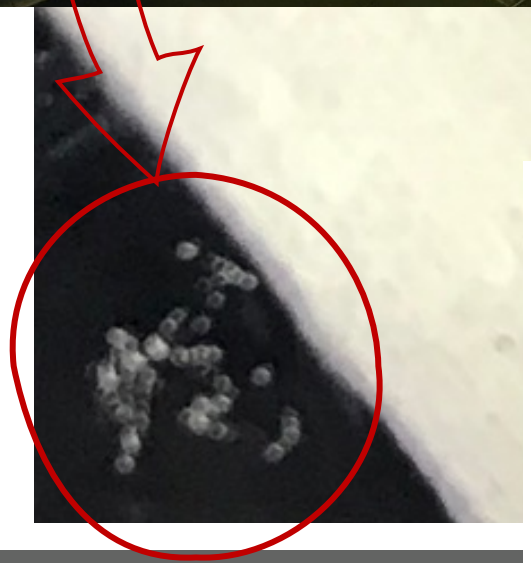
(n,p) and (n,a) reaction-induced background studies at LANSCE

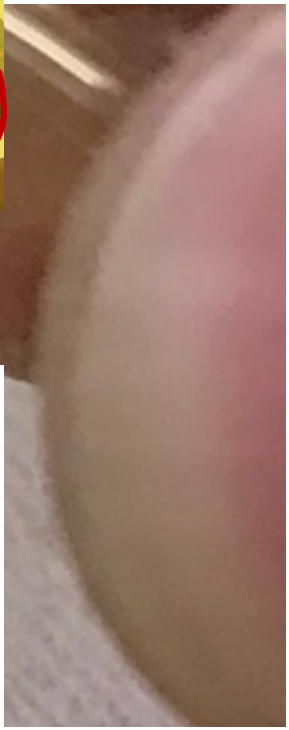
Kapton double layers cause worse resolution for charged particles due to straggling

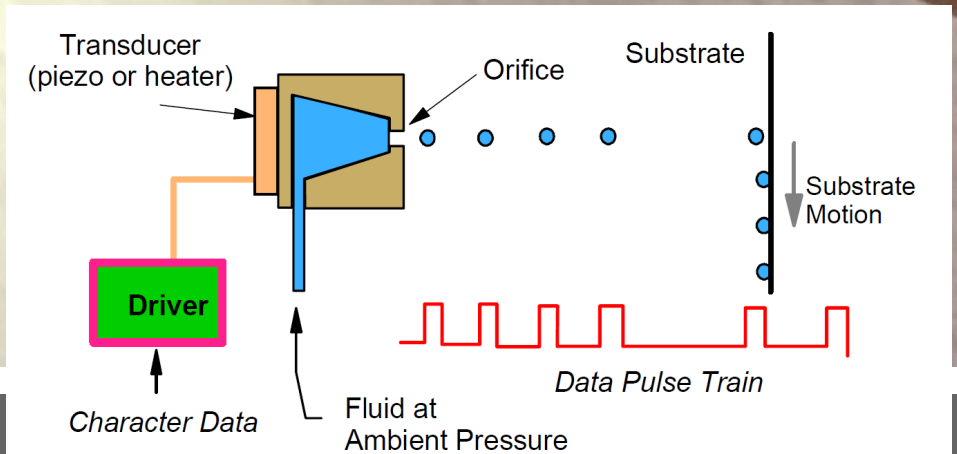
Stippling method is difficult to perform uniform thin deposit

Microjet plating at IPF/LANSCE:



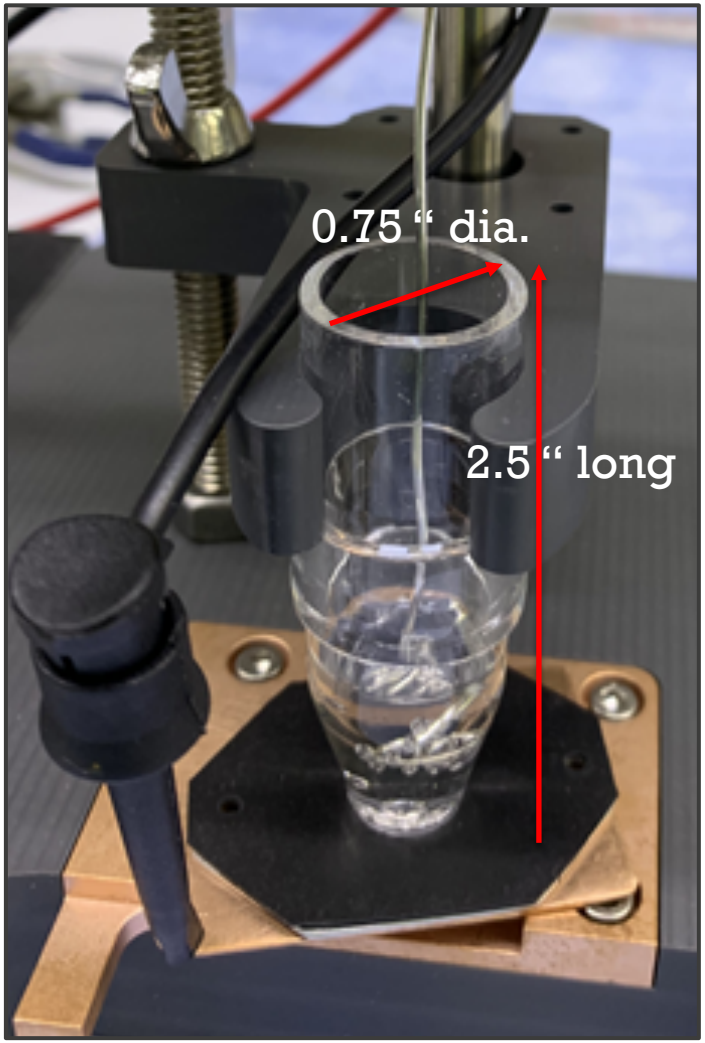






^{56}Ni and ^{57}Ni Electro-deposition

Courtesy of Lledo



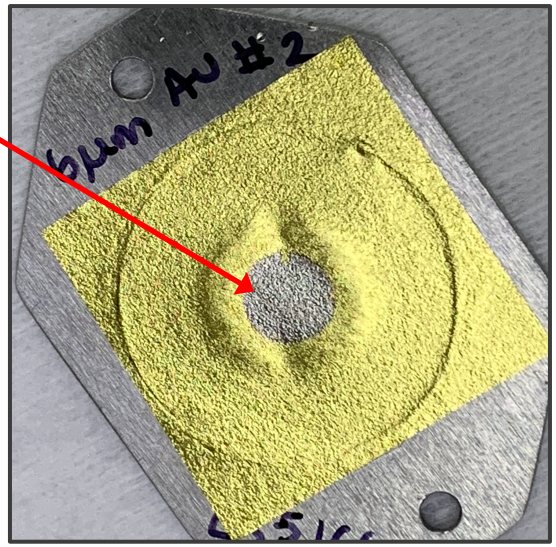
$$Ni^{2+} + 2e^- \rightarrow Ni^0$$

Simple plating conditions

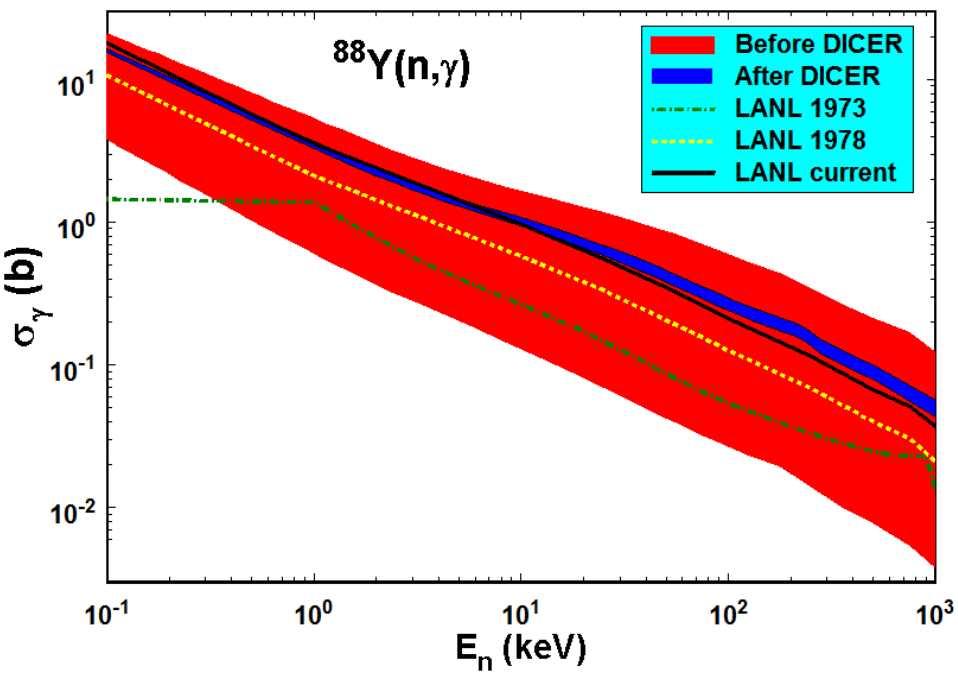
- $(NH_4)_2SO_4$ as electrolyte support
- Buffered pH 9 [NH_4OH/NH_4Cl]
- Constant current (1 mA) for 2-4 h

- Demonstrated at mass with stable Ni
- Massless samples with ^{59}Ni
- Characterization (SEM/EDS, γ-spectroscopy)

Active target diameter = 6 mm, electroplated



Device for Indirect Capture Experiments on Radionuclides (DICER) for better understanding RadChem diagnostics

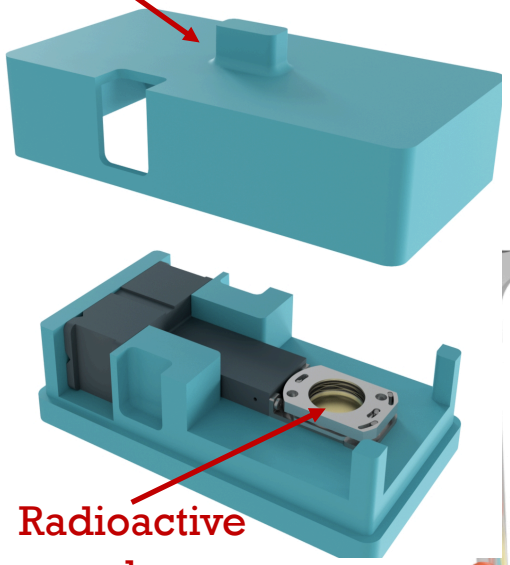


- Develop the capability to tightly constrain (n,γ) cross sections of highest importance to radchem and use them to advance predictive understanding of device performance
  Currently uncertainties much too large
  Preliminary work indicates that DICER will reduce uncertainties by large factors
- Demonstrate this capability by applying technique to ^{88}Zr (83.4 d) and ^{88}Y (106.6 d)
- Target requirements: small quantity & small diameter, like a "pencil lead" shape for precision transmission measurements

Nuclide	Mass (μg)	Diameter (mm)	Activity (Ci)	Area Ratio (Bk/sample)	Activity Ratio (sample/larger Bk)
^{88}Zr	1.1	1.0	0.020	2.56	0.022
^{88}Y	138	0.1	1.9	256	2.0
^{249}Bk	500	1.6	0.082	1	0.088
^{249}Bk	5650	1.6	0.93	1	1

Radioactive target handling and transport

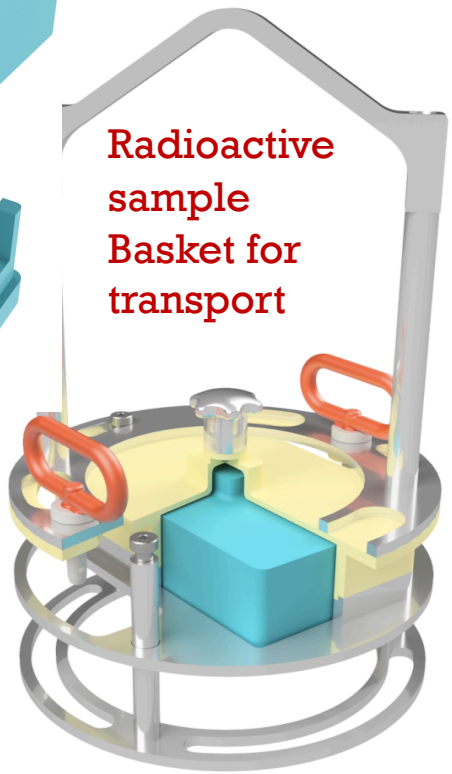
Radioactive sample housing for hot cell manipulator operation

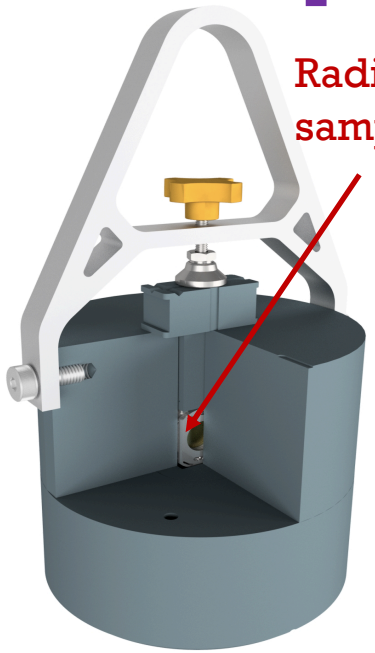


Radioactive sample

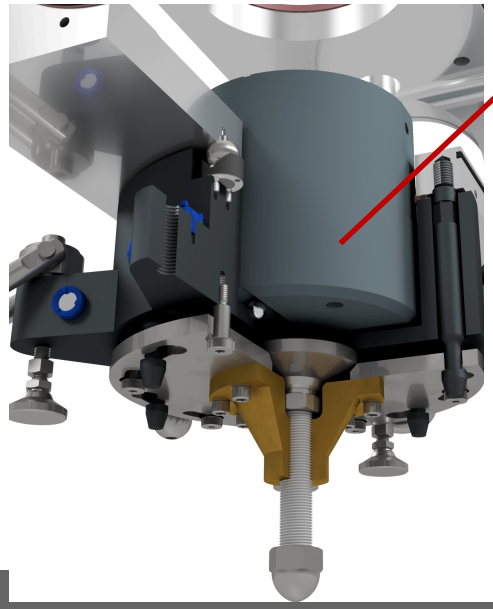
Inside Hot cell

Radioactive sample Basket for transport

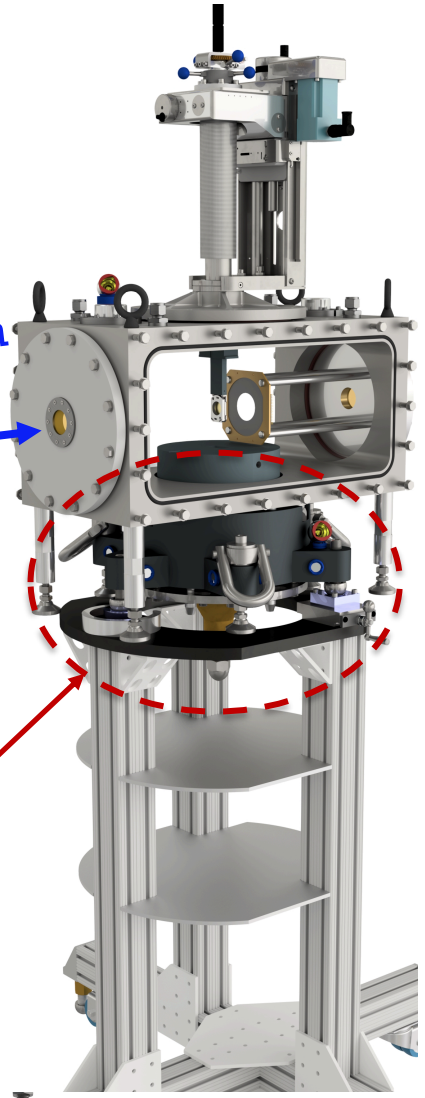




Radioactive sample



Neutron beam



Radioactive target characterization outlook

- Can leverage with existing material science characterization techniques, when simple & fast
- Continue to use nuclear physics techniques, as applicable due to target activity
- With such a small quantity radioactive targets, new collaborations are initiated like with "nano-material" scientists, etc.
- Currently, target characterization is ongoing effort to establish reliable methods
- In addition to a small quantity target, various form factors are inquired by nuclear physics community, such as a large active area with a thin, uniform film deposit vs. a long target thickness with a small diameter (~ mm)
- Any technique used for radioactive targets characterization, should be able to operate/reside inside Hot Cells